THERMAL ELECTRIC POWER STATIONS

USE OF HONEYCOMB SEALS IN STEAM TURBINES

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The appropriateness of using honeycomb seals in steam turbines is examined and the effective efficiency of using them is evaluated. It is shown that using honeycomb seals in the regulated stages and, in some cases, in the first unregulated stages, for the pressure in the high pressure cylinder, may be accompanied by losses of stability of the unit and the appearance of low frequency vibrations. Some examples of designs for seals in steam turbines with long lifetimes and enhanced antivibration properties proposed by leading foreign companies are discussed.

Keywords: steam turbine, high pressure cylinder, seals, honeycomb seals, aerodynamic forces, low-frequency vibration stability.

One way of increasing the relative internal efficiency of a cylinder and of a turbine assembly as a whole is to improve the seals. Here the most important factor is their operational reliability, the retention of sealant properties between repairs, and their repairability.

Honeycomb seals have recently come into wide use [1 – 5]. They have been introduced in new turbine designs and are recommended for use in rebuilding existing assemblies. The introduction of honeycomb seals was also discussed at an All-Russian conference-seminar of technical managers at the DZO of JSC RAO "EÉS Rossii" held on November 22 – 23, 2007. (The talks by R. G. Milyaev, the chief engineer of JSC "OGK-1," and A. A. Salikhov, the deputy head of the administration department of the scientific-design and repair-service group JSC RAO "EÉS Rossii," have been published on the internet.) In the meantime, data on the comparative efficiency, durability, and repairability of honeycomb and standard labyrinth seals presented in these talks are often not adequately justified, are contradictory, and, in some cases, are not entirely correct.

We believe that the data given in some individual sources [2] and in the talk by Salikhov, which indicate an increase of 5 – 7% in the internal efficiency of a cylinder or turbine after repairs and installation of honeycomb seals, should be rejected. It is impossible not to agree with Milyaev (and this is confirmed by some elementary calculations) that these results could only have been obtained for an absolutely worn flow-through section; they are evidence of prior repair work of low quality and operational performance, rather than an indication of the quality of honeycomb seals. Thus, only those results demonstrating an efficiency increase by 1 – 1.5%, and no more, should be considered.

But even this level of efficiency for the honeycomb seals, as indicated by major developers and the most competent researchers, primarily from a group at the Bryansk State Technical University [1, 5], is not absolutely correct when the seals of existing design are replaced by honeycomb seals. First of all, any enhanced savings following the introduction of honeycomb seals should be compared with the warranted performance of the turbines, which has been verified repeatedly. Second, the results of tests immediately following repairs should be compared with similar test data at the end of the inter-repair period, rather than making purely inductive and, we believe, utterly false, assumptions about low wear in honeycomb seals. All of these things, plus the fact that, in most cases, the geometry of the honeycombs used in rebuilding turbines is far from optimal [5], suggest an actual efficiency of honeycomb seals in the flow-through section of the high pressure cylinders (HPC) of no more than 0.7 – 1.25% compared to the traditional seal designs used in domestically produced turbines.

The largest Russian energy production units on which honeycomb shroud seals have been introduced are the K-300-240 turbines at the Kashira GRÉS (State Regional Electric Power Plant) of JSC "OGK-1" which were manufactured by the LMZ factory. The shroud seals were rebuilt

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during major repairs by the TsRMZ factory of JSC "Mosénergo" using honeycomb seals manufactured by FGUP NPP "Motor" (Ufa, Russia). Tests by experts from the subsidiary JSC "Inzhenernyi tsentr EÉS" of the "Firma ORGRÉS" confirmed that the efficiency of the high pressure cylinder was raised by 1.25%.

In addition, the use of honeycomb seals in the high pressure cylinders of supercritical turbines requires special attention, since they can cause an intensification of aerodynamic circulation forces.

Aerodynamic forces capable of exciting low frequency vibrations of high power steam turbines were first discovered in 1958 [6]. However, until assemblies with powers of 300 – 500 MW came on line, it was assumed that it was not these forces, but primarily nonconservative positional forces that develop in the grease film of bearings, which cause the low frequency vibrations (except in cases of turbines with light, flexible rotors).

Low frequency vibrations with an overwhelming influence of aerodynamic perturbations was first found in a K-300-240 KhTGZ (Kharkov) turbine [6]. The characteristic feature in this case was a load threshold, which, when crossed, rapidly led to intense vibrations. A K-300-240 LMZ turbine behaved similarly, although somewhat more mildly. But the biggest problems arose with a T-250/300-240 TMZ turbine, for which the load threshold in the initial stage of operation was less than 60% of the nominal value. It is then that the problem of low frequency vibrations (LFV) came to the attention of the major departments headed by A. G. Kostyuk, V. I. Olimpiev, and B. T. Runov.

Many papers, in particular Refs. 6 – 8, have dealt with low frequency aerodynamic perturbations of rotors. Based on these papers, we can say that in a flow-through portion there are many sources of forces that can produce low frequency rotor vibrations. The forces themselves can be divided into three groups:

— wheel, determined by variations in the peripheral forces on the working blades owing to nonuniform flows of steam over the surface of the shroud (peripheral) seals;

— shroud, associated with a peripheral nonuniformity in the steam pressure in the channels of the shroud seals that arises when the rotor vibrates; and,

— labyrinth, which arise in the channels of developed seals, primarily intermediate ones, and are associated with twisting of the flow in these channels.

Calculations confirmed that the overall severity of the aerodynamic forces in the turbine from the Kharkov factory is the greatest, because, in this turbine, the width of the shrouded blades of the high pressure cylinder is greatest and the designed gaps above the shroud (because the cylinder is supported on lugs in the upper half of the cylinder during construction) are the smallest. This led to a significant increase in the shroud and wheel forces. In addition, as the unit power is increased with an associated increase in the width and height of the working blades, the shroud forces generally begin to predominate over the wheel forces [6]. Under these conditions, neither the segmented bearings that were used, nor a change in the loading on the bearings offered a reliable way of avoiding LFV. The only way of eliminating LFV at that time was thinning of the flow through section in the zone of the regulated stage and in the first unregulated stages for the pressure in the inner cylinder.

During finishing of the T-250/300-240 TMZ turbine, the factory staff paid close attention to the scientist's recommendations and studied the experience of the battle with LFV in other turbines. With their combined efforts, the LFV problem was solved at its source. First, axial-radial shroud seals with a sufficiently low level of perturbing aerodynamic forces were developed and introduced. These seals reduced the problem of LFV excitation by aerodynamic forces to such an extent that it was not necessary to use segmented bearings, although the bearing load was significantly lower and the rotor flexibility was greater in the HPC and MPC-1 (medium pressure cylinder) of the T-250/300-240 turbine than in the other turbines listed above. The LFV problem subsequently arose in this turbine only in the form of grease vibration in the bearings for MPC-2 and LPC (low pressure cylinder), and was mainly caused by wear of these bearings during startup and shutdown processes, since this turbine did not (and, unfortunately, still does not) include a system for hydrostatic lifting of the rotors.

Returning to the question of seals for the flow through portion of the HPC, it is unacceptable that all the experience gained in the battle with LFV should be ignored. Referring to a warning by one of the authors of this article, in his talk R. G. Milyaev states that installing honeycomb seal above the shroud in a K-300-240 LMZ turbine would not lead to the appearance of LFV. However, the warning to which Milyaev referred, concerned the K-800-240 turbine, where the circulatory forces are considerably greater than in the K-300-240 turbine, although, even there, the discussion was primarily about the seals in the stages of the inner cylinder.

In addition, greater emphasis should be placed on the fact that the honeycomb seals in the example cited by Milyaev were only installed in stages 3 through 12, while calculations show that the forces that develop in the regulating and second stages constitute more than 75% of all the nonconservative forces on the HPC in a K-300-240 LMZ turbine. We could only rejoice in the success of the JSC "OGK-1" firm if, in his talk, Milyaev had not added that, in the opinion of the experts at ORGRÉS, when the regulated and first unregulated stages of the HPC are fully equipped with shroud honeycomb seals the cost efficiency of the HPC could be increased by another 1 – 1.5% and more. How could they not have recalled the comment of the leading turbine construction specialist, the former chief designer of the UTMZ, D. P. Buzin, to the effect that the most economical turbine is one that never runs. There is every reason to assume that carrying out the recommendation that the seals be installed in the first two stages should also yield the most economical turbine.

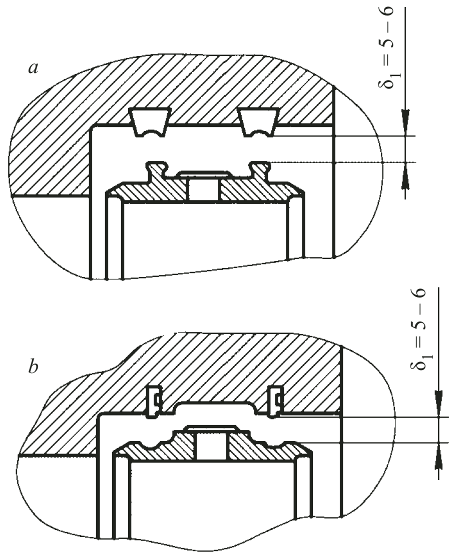

Fig. 1. Illustrating wear on a seal above the shroud with nibs on the shroud (*a*) and at the edges of the baffle (*b*).

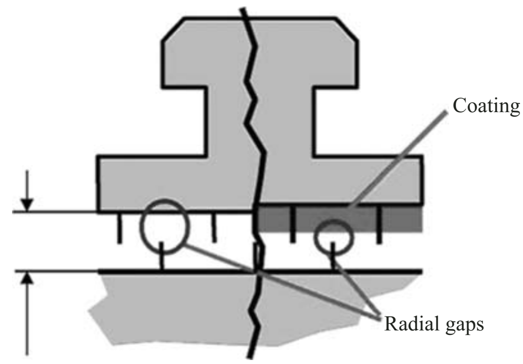

Fig. 2. A seal design from Siemens [11] with soft inserts.

Up to now, in our discussion of introducing shroud honeycomb seals, we have actually been discussing the problem of reverse replacement of axial radial shroud seals by previously used radial seals. Regardless of whether use is made of inserts of metal ceramic or armco iron which are installed opposite the nibs beforehand, or of honeycomb seal units, as is now proposed, it must be acknowledged that this is still a standard radial seal. And for this reason we consider it necessary to recall the possible consequences of replacing the seals in the stages of the high pressure section, as well as in the intermediate seal of the HPC [9]. In its time, in the T-250/300-240 turbine, as well, it was proposed that axial-radial seals be used only in the inner casing of the HPC. But studies from that time which confirmed that these seals wear less, and their average efficiency curing the inter-repair period exceeds that of radial seals, led to more widespread use of axial-radial seals. Thus, they began to be used in the medium and low pressure sections, as well as in turbines with lower steam parameters, where the aerodynamic nonconservative forces are negligible.

The switch to honeycomb seals is still a switch to direct-flow seals. There is no doubt that the efficiency of these seals is lower. Plots [3] of the flow coefficient through seals with honeycomb inserts show clearly that for a gap greater than 0.5 mm, even with five nibs and the existing peripheral velocities, the flow coefficients exceed unity. The recommendation that a gap of 0.15 – 0.25 mm be made in the end seals of the MPC and the LPC indicates that, from the start, it is possible to brush against the nibs of the honeycomb assemblies, since these gaps are considerably smaller than both the amounts of levitation of the rotor at the large diameter bearings and the allowable vibration of the rotor at the critical and working rotation frequencies.

Therefore, the only sure advantage of honeycomb seals is that honeycomb assemblies are softer and more easily cut through, so the nibs will be subjected to less wear. However, first of all, given the technology for manufacturing honeycomb assemblies, is this not an excessively costly way to achieve this and, second, shouldn't account be taken of the fact that, other conditions being the same, the wear on honeycomb inserts will be very substantial? And it can be seen from a figure given in Salikhov's talk (Fig. 1) that gaps of 5 – 6 mm may develop during operation of a turbine with relative radial displacements of the rotor by essentially the same 5 – 6 mm. We can say with the greatest probability that this kind of wear most likely occurs as the rotor passes through its critical rotation velocities. When honeycomb seals are used, all of the wear will be concentrated in the honeycomb assemblies. But here it should be kept in mind that this will not by any means just be narrow notches in the assemblies.

Given the variable relative expansions during the transition through the critical rotation velocities, since the turbine is started up in various thermal states, even in the radial direction the wear on the honeycomb seal assemblies will be significant. Some idea of the wear on the inserts can be gained from this same Fig. 1. It is also impossible to ignore the distortions in the components of the housing, the change in the heightwise position of the cylinder housing relative to the axis of the bearings, the levitation of the rotor in the bearings, and other factor, so that to conclude that honeycomb seals can be installed with essentially zero gaps is nonsense. For just this reason, honeycomb seals have come into widespread use, especially in aviation engine construction, where the relevant conditions are considerably different than in steam turbines.

Less often, honeycomb seals made of high chromium steels are used in stationary gas turbines, such as those manufactured by GE, in which, as in aircraft engines, heat resistance of the components in the flow through section is of the greatest importance. At the same time, Siemens uses similar seals with a much cheaper carbon or composite coating created by multilayer deposition or sputtering of the materials (Fig. 2). In domestic turbine building, as well, there is a fair

Fig. 3. Design of the clasp mechanism for seal segments from Siemens [11].

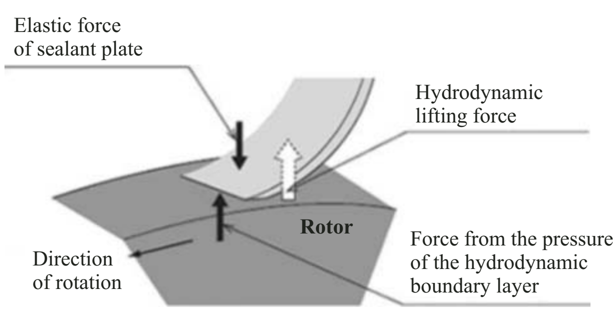

Fig. 4. Lobed radial shroud seals from Mitsubishi [12].

amount of experience with the use of graphite bushings. But, in any case, when soft materials are used it is not intended that something should be cut, but that in those exceptional cases of damage, the maximum integrity of the seals should be maintained, both of the design of the component, itself, and of its properties.

In order to make brushing of the moveable and fixed portions of the seals an exceptional occurrence and reduce the probability that this can happen, a comprehensive approach is required.

The first element of this approach, which is important for any seal design, is to reexamine the specifications for balancing the rotors on balance test stands and in operation. In particular, existing standards for the quality of balancing on balance test stands with respect to vibration of the supports or to dynamic loads on the supports, do not, in practice, exclude unacceptably large elastic flexure of the rotors at the critical rotation frequencies. At the same time, the standards for balancing quality at companies in the US, Japan, and UK, do take rotor flexures into account, including those at critical rotation. Work is under way to solve the problem of setting standards for modal rotor imbalances during balancing, both on test stands and when mounted on the operating bearings [10].

The second element of a comprehensive approach is the use of diaphragm, intermediate, and end seals with automatically regulated gaps. Up to now, the domestic designs have employed seals in which the segments of the seals are compressed by flat springs. Experience shows that the antiwear efficiency of these designs is inadequate. At the same time, foreign designs employ seals with segments that are, on the other hand, compressed in their initial state and, thereby, enlarge the radial gaps during startup and shutdown of the unit. The design shown in Fig. 3 is an example of a seal of this type [11]. The helical springs mounted in the ends of the seals, compress them, thereby increasing the diameter of the seals. Once the required pressure in the flowthrough section and, therefore, the required pressure in the chamber above the shelves of the segments, is attained, the segments are displaced as they compress the helical springs and shift closer to the shaft. Use of this kind of seal design (or an effective equivalent) can ensure maximal efficiency for seals of any type, including honeycomb seals.

At the same time, leading foreign firms have undertaken fundamentally new design solutions for seals; in particular, for the space over the shrouds in the regulator stages, wiper [11] or analogous lobed [12] (Fig. 4) seals have been developed. Composed of a large number of lobes positioned close to one another over the circumference, they are compressed by the elastic force and pressed outward by the aerodynamic force that develops in the boundary layer. These essentially contactless seals ensure a constant radial gap and, therefore, prevent the formation of circulatory aerodynamic forces.

In conclusion, it should be noted that it is incorrect to compare the efficiencies of domestic and modern foreign turbines, as done in the talk by A. A. Salikhov, the representative of the RAO "EÉS Rossii." This is so, first, because, the efficiency of foreign turbines is determined not just by the quality of the seals, but also by many other improvements in the economics of the flow-through segment, including a three dimensional design for the blade assembly, and, second, as even this brief review of seal designs shows, the existing lag in design solutions may be regarded as close to critical.

REFERENCES

1. V. T. Buglaev, *Honeycomb Seals in Turbine Machinery* [in Russian], Izd. BGTU, Bryansk (2006).
2. M. P. Yushka and S. V. Ushinin, "Use of honeycomb seals in turbines," *Élektr. Stantsii*, No. 6 (2005).
3. Yu. M. Brodov and V. V. Kortenko (eds.), *Steam Turbines and Turbine Units from the Urals Turbine Factory* [in Russian], Aprio, Yekaterinburg (2007).
4. Yu. M. Brodov and V. N. Rodin (eds.), *Steam Turbine Repair* [in Russian], Izd. GOU VPO UGTU-UPI, Yekaterinburg (2005).
5. V. T. Buglaev, V. T. Perevezentsev, and A. L. Kartashov, "Enhancing the reliability and economy of steam turbines using honeycomb seals," in: *Proc. V^th Int. Sci.-Pract. Conf. on* "*Improvement the Thermotechnical Equipment*, *Reconstruction of Thermal Power Stations*, *Introducing Service*, *Diagnostic*, *and Repair Systems*," Nauka-Servis, Yekaterinburg (2007).

6. B. T. Runov, A. Z. Zile, and M. N. Rudenko, “Stability of high pressure rotors in steam turbines,” *Élektr. Stantsii*, No. 6 (1976).
7. A. G. Kostyuk, *Dynamics and Durability of Turbine Machinery* [in Russian], Izd. MÉI, Moscow (2000).
8. V. I. Olimpiev, “The battle with low frequency shaft-line vibration in high-power steam turbine generator systems,” *Teploénergetika*, No. 9 (1978).
9. A. G. Kostyuk, S. A. Serkov, E. V. Ur’ev, and B. N. Petrunin, “The influence of the diaphragm seals of a steam turbine on the aerodynamic excitation of rotor vibrations,” *Teploénergetika*, No. 11 (1991).
10. M. M. L’vov, S. B. Ivanov, and E. V. Ur’ev, “Standardization of the residual imbalance of flexible rotors,” *Tyazh. Mashinostr.*, No. 7 (2007).
11. Michael W. Smiarowski, Rainer Leo, Christof Scholten, and John Blake, *Steam Turbine Modernization Solutions Provide a Wide Spectrum of Options to Improve Performance*, Siemens AG (2005).
12. Eiichiro Watanabe, Yoshinori Tanaka, Takashi Nakano, et al. (eds.), *Development of New High Efficiency Steam Turbine Mitsubishi Heavy Industries Ltd. Technical Review*, **40**(4) (August 2003).